Three-Year-Olds' Retrospective Revaluation in the Blicket Detector Task

Backward Blocking or Recovery From Overshadowing?

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Abstract. We presented 3-year-olds with backward blocking and recovery from overshadowing contingencies in the blicket detector task, a causal induction task that uses binary, deterministic outcomes. Results revealed recovery from overshadowing but no backward blocking. These results are consistent with recent inferential and computational models of causal learning and induction. Our findings extend and clarify recent reports of retrospective revaluation in 3- and 4-year-olds (Sobel, D. M., Tenenbaum, J. B., & Gopnik, A. (2004). Children's causal inferences from indirect evidence: Backwards blocking and Bayesian reasoning in preschoolers. *Cognitive Science, 28*, 303–333), and underscore the sophistication of causal induction processes in young children.

Keywords: causal learning, cue competition, blocking, children, causal induction

People exhibit a remarkable capability at discovering causal relationships among events that occur in their environments. In a sense, that is not surprising, as this capacity allows one to anticipate future states of the world (e.g., a likely attempt at retaliation from one's neighbour at the bar) on the basis of current conditions (e.g., one being flirted with by the partner of one's neighbour), so that one can try to prevent this future state of affairs from happening (e.g., by acting uninterested) or anticipate to cope with it (e.g., by flexing one's muscles). It is obvious that such a capacity is crucial for one's social and physical survival. Consequently, the processes and principles that underlie the human capacity for causal learning and induction have been and continue to be a topic of much interest and intense debate in philosophy, psychology, and cognitive science (e.g., Cheng, 1997; De Houwer & Beckers, 2002; Gopnik et al., 2004; Hume, 1739/1987; Kant, 1781/1965; Michotte, 1954; Pearl, 2000).

In recent years, much of the debate in the psychology of causal learning has centred around the question to what extent human causal learning relies on low-level associative processes, as embodied in the Rescorla-Wagner model (Rescorla & Wagner, 1972) and related models (e.g., Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994), or on more sophisticated inferential reasoning processes, such as those represented by Causal Model Theory (Waldmann, 1996) and computational models of causal learning (e.g., Griffiths & Tenenbaum, 2005). Much of the input in this debate has come from studies on cue competition in human causal learning. Cue competition refers to the observation that the causal status of a cue B in producing a given outcome O is not only determined by the degree of co-occurrence of that particular cue with the outcome under consideration, but also by the degree of co-occurrence of certain other cues with the outcome. For instance, blocking, one of the most intensely studied cue competition phenomena, entails the observation that the causal status of cue B, which is paired with the outcome in compound with another cue A (denoted as AB → O), will be reduced if A on itself is also paired with the outcome (denoted as A → O) either before the AB → O pairings (forward blocking) or after the AB → O pairings (backward blocking, a form of retrospective revaluation). Other forms of cue competition include overshadowing, in which the causal status of cue B is judged to be less if it is paired with the outcome in combination with another cue A (AB → O) than if it is paired with the outcome on itself (B → O), and unovershadowing, in which the causal status of B is increased if compounded parings of A and B with the outcome are accompanied by presentations of A without the outcome (A → noO), either before the AB → O pairings (protection from overshadowing) or thereafter (recovery from overshadowing, which like backward blocking is an instance of retrospective revaluation).

A wealth of research indicates that the occurrence of cue competition in human causal learning is sensitive to constraints of normative causal induction in a way that fits naturally with recent computational and inferential models of causal learning, but is at variance with core assumptions of associative models of causal learning (e.g., Beckers, De Houwer, Pineño, & Miller, 2005; De Houwer, Beckers, & Glautier, 2002; Vandorpe, De Houwer, &

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Beckers, 2007; but see Le Pelley, Oakshott, & McLaren, 2005).[1] One particularly relevant set of evidence for the present purposes comes from studies showing that the occurrence of blocking is crucially dependent on the availability of sufficient working memory resources (De Houwer & Beckers, 2003; Vandorpe, De Houwer, & Beckers, 2005; Waldmann & Walker, 2005), in line with the idea that the reduced causal strength estimate that constitutes blocking is arrived at through effortful inferential reasoning processes.

In the context of the debate between associative and inferential models of causal learning, recently, attention has been devoted to the study of cue competition in causal learning and induction in children (e.g., Beckers, Van den Broeck, et al., 2005; Sobel, Tenenbaum, & Gopnik, 2004; Waldmann & Weber, submitted for publication; see also Gopnik et al., 2004). If blocking and other cue competition phenomena rely in part on effortful inferential reasoning processes (e.g., De Houwer & Beckers, 2003) and insight in causal mechanisms (e.g., De Houwer et al., 2002; Waldmann & Holyoak, 1992), one might perhaps expect that blocking would be less likely to occur in preschool children, who presumably possess less working memory capacity (e.g., Luciana & Nelson, 1998), and have been claimed to lack true understanding of causal mechanism (e.g., Schlottmann, 2001). Alternatively, blocking, if it occurs in preschool children, might reflect the operation of simple associative processes, rather than sophisticated causal induction processes, and thus be less sensitive to normative constraints of causal induction.

Most of the limited evidence that is presently available seems to support inferential models. Waldmann and Weber (submitted for publication), for instance, in a causal learning study comprising different age groups, observed that cue competition only occurred in participants of 7 years of age and beyond; when it did, it was sensitive to the causal structure of the task. Beckers, Van den Broeck, et al. (2005) presented 4- and 8-year-old children with a contingency learning task, which was embedded in either a causal or a predictive scenario. In this task, the children were asked to predict the degree of rain depicted on the back of a card, on the basis of coloured symbols on the front of it. Half of the children were told that the coloured symbols represented buttons on a machine that could produce rain (causal scenario), whereas the other half of the children were told that the symbols represented indicators on a machine that could predict rain (predictive scenario). In line with Causal Model Theory and inferential reasoning models of causal learning, blocking occurred only in the causal scenario, and not in the predictive scenario. Importantly, unlike in the study by Waldmann and Weber (submitted for publication), there was no effect of age group, suggesting that blocking does occur in preschool children if probed with a task that is sufficiently intuitive and appealing to them, and that children can exhibit rather sophisticated causal induction capabilities even at age four.

Finally, Sobel et al. (2004, Experiments 1–2) obtained evidence for cue competition in 3- and 4-year-old children, using a blicket detector task. In this task, children were presented with blocks of various shapes and colours, which when placed on the blicket detector (a wooden box) could make the machine buzz and light up (in which case the block is a blicket) or not (in which case the block is not a blicket). They first presented the children with two blocks (say A and B) that, when placed on the machine together, made it go off. Afterwards, block A was placed on the machine on itself and this made the machine either go off or not. Crucially, children's judgement of whether block B, which was never placed on the machine on itself, was a blicket, was significantly affected by the causal status of A, such that the children judged B less likely to be a blicket if A was a blicket than if A was not a blicket.

Sobel et al. (2004) describe their findings as evidence for backward blocking and recovery from overshadowing (which they term "indirect screening off"). However, it is actually unclear whether their results reflect only backward blocking, only recovery from overshadowing, or both. That is, the difference in causal status of B between the backward blocking and the recovery from overshadowing conditions may have been due to the A $\rightarrow$ O trials decreasing the causal status of B below what it would have been without the A $\rightarrow$ O trials (backward blocking), the A $\rightarrow$ noO trials increasing it above what it would have been without the additional A-only trials (recovery from overshadowing), or both. In the absence of a control condition, in which A is not placed on the blicket detector on itself, this is not amenable to evaluation. This issue is not without importance, though. Although Sobel et al. interpret their results as favouring a normative Bayesian structure learning account of causal induction, most normative models of causal induction would not actually anticipate backward blocking to occur in the task that was employed. For instance, according to the power PC model (Cheng, 1997), if a binary outcome always occurs when either A and B are present or A is present alone, the causal status of B cannot be determined. In other words, the A $\rightarrow$ O trials do not help to clarify the causal status of B. However, unlike A $\rightarrow$ O trials, presentation of A $\rightarrow$ noO trials should help to disambiguate (i.e., increase) the causal status of B. In other words, according to the power PC model (or any computational model of causal learning that incorporates a Noisy-OR parameterisation, e.g., Griffiths & Tenenbaum, 2005), in the blicket detector task as used by Sobel et al. (2004, Experiments 1–2), recovery from overshadowing rather than backward blocking should be responsible for the retrospective revaluation that is observed.

In contrast, associative models of causal learning would have no problem accounting for the occurrence of backward blocking in this task. For example, according to the revised Rescorla-Wagner model (Van Hamme & Wasserman, 1994), presentation of A-only trials after AB $\rightarrow$ O trials will result in changes of the causal status of B because of the fact that

[1] In fact, recent evidence suggests that also nonhuman learning may in whole or in part be attributed to the operation of inferential reasoning processes. For instance, the appearance of forward blocking in Pavlovian conditioning in rats seems to be sensitive to constraints of causal inference, such as outcome maximality (e.g., Beckers, Miller, De Houwer, & Urushihara, 2006).

Table 1. Design of the experiment

Condition	Trials
Backward blocking	AB+ CD+ E− A+
Recovery from overshadowing	AB+ CD+ E+ A−
Control	A+ E−

Note. A, B, C, D, and E represent blocks of different shapes and colours; "+" indicates activation of the blicket machine, "−" indicates no activation of the blicket machine. The trial series was repeated twice in each condition. The backward blocking and recovery from overshadowing conditions were presented twice, the control condition once to every participant, using new blocks each time, in a semi-random order. See main text for further details.

the presentation of A activates the representation of B through the A-B association established on the AB → O trials. As a result, the causal status of B will change in a direction opposite to the change in the causal status of A. In the case of A → O trials, the causal status of A will go up and the causal status of B will go down; similarly, in the case of A → noO trials, the causal status of A will go down and the causal status of B will go up. So, according to such models, backward blocking will occur under the same circumstances that recovery from overshadowing occurs under, and vice versa, because they are assumed to be symmetrical results of the same basic learning algorithm.

In causal learning in adults, unovershadowing is typically much stronger than blocking (Vandorpe & De Houwer, 2005). Also, recovery from overshadowing has been shown not to be sensitive to the same constraints of causal induction as is the case for backward blocking (Beckers, De Houwer, et al., 2005, Experiment 3; Lovibond, Been, Mitchell, Bouton, & Frohardt, 2003). This suggests that backward blocking and recovery from overshadowing are not (always) symmetrical outcomes of the same learning mechanism. More specifically, for human adults as well as rats, evidence suggests that subjects are sensitive to the fact that outcome maximality obscures the causal status of a blocked cue B in a blocking design that includes appropriate controls (Beckers, De Houwer, et al., 2005; Beckers, Miller, De Houwer, & Urushihara, 2006).

The aim of the work reported here was to establish to what degree the retrospective revaluation that 3-year-olds display in the blicket detector task is driven by backward blocking, recovery from overshadowing, or both. If causal induction in such young children relies on more basic associative principles than it seems to do in adult humans (e.g., Schlottmann, 2001), one could anticipate both to contribute equally to retrospective revaluation. However, if 3-year-old children's causal learning reflects fairly sophisticated causal induction capabilities (e.g., Beckers, Van den Broeck, et al., 2005), one should expect retrospective revaluation in this task to be driven by recovery from overshadowing only.

To test these alternatives, we adapted the blicket detector task used by Sobel et al. (2004), including trials on which two blocks C and D were placed on the detector and resulted in activation of the machine, and without presenting trials on which only C or D would be placed on the machine (see Table 1). This way, judgements for C can serve as a comparison to evaluate the effect of A → O and A → noO trials on judgements for B. So, in some series of trials, children saw the blicket detector getting activated when A and B were placed on the machine together, when C and D were placed on the machine together, and when A was placed on the machine alone, whereas it did not get activated when another block E was placed on the machine alone (backward blocking condition). Afterwards, they were asked about A, B, and C whether or not each was a blicket, and were asked whether they would choose either B or C if they wanted to activate the machine. A backward blocking effect would be evident if B was judged less often to be a blicket than C, and if children preferred C over B to make the machine activate. In other series of trials, the children were asked the same questions after seeing the blicket detector getting activated when A and B were placed on the machine together, when C and D were placed on the machine together, and when E was placed on the machine alone, whereas it did not activate when A was placed on the machine alone (recovery from overshadowing condition). A recovery from overshadowing effect would imply that they judged B more often to be a blicket than C, and if they preferred B over C when asked to activate the machine.

Method

Participants

Forty-seven children (20 girls, 27 boys) with a mean age of 40 months (ranging from 34 to 46 months of age) participated in the experiment. They were recruited from a kindergarten in the city of Leuven. Written informed consent was obtained from the children's parents before the start of the study; the children gave oral consent right before participating.

Stimuli and Materials

For the pretest, two identical yellow plastic bars and two identical transparent plastic cubes were used. For the actual experiment, 30 wooden blocks were used, all different in colour and shape.

The blicket detector was constructed after the device used by Sobel et al. (2004). It was a wooden box, $24 \times 16 \times 8$ cm ($l \times w \times h$), with a semi-transparent grey plastic top. An electrical cord with a power switch came out of one side of the box. The box contained pressure-sensitive sensors underneath the plastic top, such that when the power switch was on and a block was placed on the device, a bell would sound and the plastic top of the box would light up. The box was placed on top of a table, between the child and the experimenter, such that the child could not see the electrical cord coming out of the device and the experimenter could easily control the power switch out of sight of the child.

Procedure

The experiment consisted of a pretest, a training phase, and an experimental phase that contained five conditions.

The pretest was conducted to see whether the children were capable of learning new categories of objects. They were presented with the yellow bars and the transparent cubes, after which the experimenter picked one of the objects and said it was a "flop". The child was then asked whether it could give the experimenter the other flop. This routine was repeated with a different object, which was called a "dap" by the experimenter. If the child pointed to the object identical to the one picked up by the experimenter on both trials, testing proceeded to the next phase; if not, the experiment would be aborted. All children passed the pretest.

In the training phase, the blicket detector (called "fonkel machine" in Dutch) was introduced to the children. They were shown a basket with the blocks, and given the following instructions (translated from Dutch): "*Here is a blicket machine, and a bunch of blocks. Some of these blocks are blickets ('fonkels') and some are just regular blocks. We don't know which ones are blickets and which ones are not. To find out which blocks are blickets, we use the blicket machine. You can place one or more blocks on the machine, and the machine tells us when there is a blicket on it by lighting up and making a sound. Look.*" The functioning of the machine was then demonstrated by the experimenter by placing one block on the machine that made the machine go, and then placing one block on the machine that did not make it go. The experimenter then tested whether the child had understood the instructions, by placing one block on the machine that made it go and one block that did not make it go, one after the other in random order, and afterwards asking the child which block was a blicket. This was repeated, using new blocks each time, until the child identified the correct block as a blicket three times in a row.

In the experimental phase, all children were presented with five series of trials. In two *backward blocking* series, the children were first shown that two blocks (A and B), when placed on the machine together, made it go, as did two different blocks (C and D). Then another block (E) was placed on the machine on itself and did not make the machine go. Finally, block A was placed on the machine on itself and did make the machine go. After that, the whole sequence of trials was repeated, in the same order. The two *recovery from overshadowing* series were identical to the backward blocking series, except for the fact that block E now did make the machine go on itself, whereas A did not. In the *control* series, one block that was placed on the machine on itself did make it go on both trials, whereas another one never did. The five series were presented in a new random order for each child, with the restriction that the control series was never presented first. New blocks were used for each series, so that a child never saw the same block in different series. At the end of each backward blocking and recovery from overshadowing series, after the sequence of trials was presented, the children were first asked which block they would pick to make the machine go when given the choice between blocks B and C, and then, without feedback concerning the first question, they were asked whether or not each of blocks A, B, and C was a blicket. At the end of the control series, they were merely asked whether A was a blicket and whether B was a blicket. The control condition simply served to check whether children still knew that a block that made the machine go was a blicket and one that did not was not. Two children (both boys) failed this test; their data were excluded from the analyses, leaving 45 children in the final sample.

Results

For each of the two conditions (backward blocking and recovery from overshadowing), we recorded how often the children labelled each of the blocks A, B, and C as blickets, and how often they picked B or C to make the blicket machine go.

Figure 1 depicts the number of times each block was labelled a blicket, by condition (note that both conditions were presented twice, so the number ranges from 0 to 2). Block A was labelled a blicket more often in the backward blocking condition than in the recovery from overshadowing condition, as confirmed by a Wilcoxon signed ranks test, $z = 5.65$, $p < .01$, indicating that the children did register the fact that A was followed by the outcome in the blocking conditions but not in the recovery from overshadowing conditions. Nevertheless, in neither the recovery from overshadowing nor the backward blocking condition did the number of times B was labelled a blicket differ from the number of times C was labelled a blicket, $z = 1$, $p = .32$, and $z = 0$, $p = 1$, respectively.

Figure 2 depicts the relative number of times the children picked B or C to make the machine go in the forced-choice test in each condition (again, the preference score for each block ranges from 0 to 2). In the backward blocking condition, the numbers of children that chose block B over block C never, once, or twice did not deviate from chance as

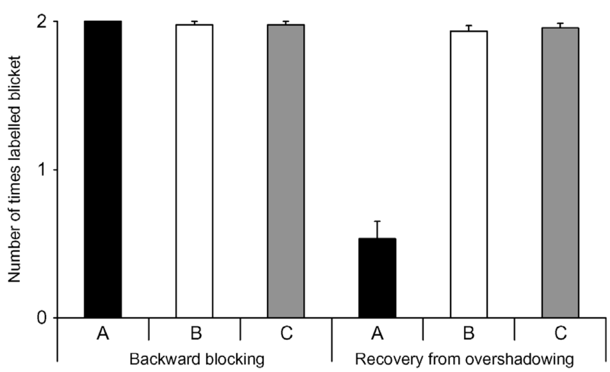

Figure 1. Mean number of times blocks were labelled as blickets after the backward blocking and after the recovery from overshadowing series. Error bars represent standard errors of the means.

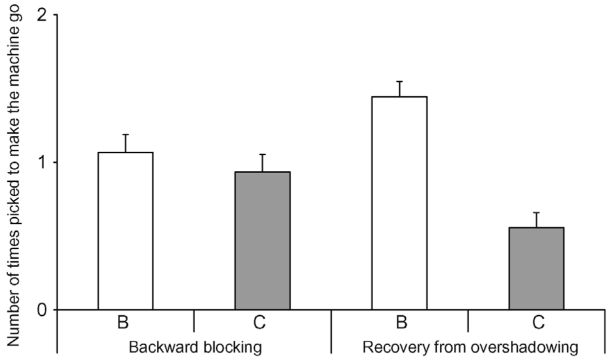

Figure 2. Mean number of times children picked block B or C to make the blicket detector go in the forced-choice test after the backward blocking and after the recovery from overshadowing series. Error bars represent standard errors of the means.

assessed by a Chi-square test calculated against a binomial distribution, $\chi^2(2) = 4.16$, $p = .13$. In the recovery from overshadowing condition the children clearly preferred block B over block C, $\chi^2(2) = 22.78$, $p < .01$. Accordingly, a Wilcoxon signed ranks test revealed that the children picked block B rather than block C more often in the recovery from overshadowing condition than in the backward blocking condition, $z = 2.29$, $p < .05$.

Discussion

The children labelled blocks B and C as blickets equally often, both after the backward blocking and the recovery from overshadowing series. However, when forced to choose between B and C to make the machine go, they clearly preferred B over C after the recovery from overshadowing series, but did not prefer C over B after the backward blocking series. The lack of difference between how often B and C were labelled blickets in the recovery from overshadowing condition cannot be interpreted because of the presence of a ceiling effect. Given that the children already tended to always label block C as a blicket, there was no room for the A → noO trials to increase the likelihood that B would be labelled a blicket. In contrast, there was clearly ample room for the A → O presentations in the backward blocking condition to reduce the likelihood that B would be labelled a blicket, which it did not. Therefore, while the labelling data are inconclusive with regard to the presence of recovery from overshadowing, they do suggest that backward blocking did not occur. The choice data offer a more conclusive picture. When forced to choose, the children clearly prefer B over C in order to make the machine go in the recovery from overshadowing series, indicating that the A → noO presentations affected children's causal inferences. In the backward blocking condition, the children are indifferent between B and C when asked to make the machine go, suggesting that the A → O trials did not influence the causal status of B, which again implies that backward blocking did not occur. In sum, then, the present data indicate that the retrospective revaluation observed by Sobel et al. (2004) was due to recovery from overshadowing, and not due to backward blocking.

Note that even though our results are at variance with how Sobel et al. (2004) describe their results (i.e., as backward blocking), they are in fact completely consistent with their theoretical position and framework. Indeed, the fact that children exhibit understanding of the causal ambiguity of a blocked cue in case of a deterministic, binary outcome is perfectly compatible with Bayesian models of causal induction that implement a Noisy-OR logic (e.g., Griffiths & Tenenbaum, 2005). While the original results reported by Sobel et al. did not exclude an associative explanation (see Sobel et al., 2004, p. 303), the results we report here seem at variance with existing associative learning models. As such, our results supplement and clarify rather than contradict the results reported by Sobel and colleagues. In this respect, it is interesting to note that in general, the 3-year-olds seemed more likely to label blocks as blickets in our experiment than in the Sobel et al. study. A likely reason for this is that, due to the addition of the CD → O trials, activation of the blicket detector was relatively more frequent than in the original study. This may well have increased the subjective a priori likelihood that blocks would be blickets. This observation is consistent with the observation that the likelihood that blocks will be labelled blickets and the degree of retrospective revaluation is affected by instructions and demonstrations that affect the perceived relative frequency of blickets (see Sobel et al., 2004, Experiment 3).

So, just as is the case for prevention from overshadowing versus forward blocking in adult causal learning (Vandorpe & De Houwer, 2005), recovery from overshadowing seems to emerge much more readily than backward blocking in 3-year-old children, as one would normatively expect. This observation adds to the considerable complexity of causal induction processes in preschoolers observed in previous cue-competition research (Beckers, Van den Broeck, et al., 2005). This is all the more remarkable because at this age, children have not yet received any formal training in the laws of physical causality. It suggests that the initial development of the machinery for sophisticated causal inference does not require formal instruction, but can be triggered by mere interaction with the causal world.

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